ASSESSMENT OF THE EFFECTIVENESS AND ENERGY EFFICIENCY OF HUMIDITY CONTROL APPROACHES IN VACANT FLORIDA HOMES

James B. Cummings
Program Manager

Charles R. Withers, Jr.
Sr. Research Analyst

Florida Solar Energy Center, a research institute of the University of Central Florida, Cocoa, FL

ABSTRACT

In a hot and humid climate such as Florida, "snowbirds" that leave their homes for extended summer periods need guidance on effective and energy efficient methods of humidity control. Experiments were performed in seven residences to evaluate various approaches to humidity control, including providing no mechanical system control. A humidity target was identified to maintain indoor relative humidity (RH) at 65% or lower most of the time. Providing no mechanical conditioning (letting the building "float") yields relative humidity at 65% or below during hot and sunny weather in some homes, but not during cloudy weather. Setting the AC system thermostat at 85°F or 83°F yielded lower than required RH during hot and sunny weather, but it yielded insufficient RH control during cloudy weather. Furthermore, AC energy use peaks during the utility's peak demand period. Running the AC system for two hours a day (3-5 AM) yielded effective and energy efficient RH control. Operation of a dehumidifier on timer control or humidistat control provided good results with the lowest overall energy use. Operation of the space heating system to maintain 89°F (which yields 65% RH when the outdoor dew point temperature is 75°F) provides reliable RH control, with good energy efficiency during hot weather (assuming a heat pump as the heating system). However, during cooler weather, the space heating approach consumed considerably more energy. Operation of the space heating system based on humidistat control provides reliable RH control and eliminates the excessive energy use which occurs during cooler weather with the constant 89°F setting.

BACKGROUND

At its peak, about 1 million temporary residents or "snowbirds" live in Florida during the winter months leaving many homes, condominiums, and apartments vacant during the long, hot and humid summer (many homes are vacant from May through October). In some counties in South Florida, up to 15% of the residents are away during summer months (Shih, 1981). With heightened concern and awareness about mold and mildew, and their health impacts, it is important to answer several questions;

1) Is it OK to just leave the house unconditioned for four to six summer months?
2) If not, what methods of humidity control are reliable?
3) What methods of humidity control use the least energy?
4) Which methods place the least electrical demand on the utility system during peak periods?

A study was performed to assess humidity control options in snowbird homes. This study was sponsored by Florida Power & Light and carried out by the Florida Solar Energy Center (FSEC). The research was carried out in two phases, Phase 1 during 2004 and Phase 2 during 2005. In total, seven approaches to humidity control were examined, including simply closing up the house and leaving it unconditioned. Experiments were performed in three residences in 2004 and four residences in 2005 (one of the houses was common to both phases).

There are differences of opinion regarding how high relative humidity should be permitted, and for what duration. In general, RH in the 70% and above range is considered a potential risk for mold growth. ASHRAE Standard 62.1 (Section 5.10) states that RH should be limited to 65%, however, HVAC system designers and building scientists often aim to limit RH to 60% in order to provide a margin for error. For this project, the research team identified the following control targets. First, RH should stay below 70% in the vacant home essentially all of the time. Second, RH should stay below 65% most of the time. Third, the target for RH, when a space conditioning appliance was being controlled by a humidistat, was set at 62%.

It is important to understand the concept of relative humidity (RH). RH, expressed in percent, is the measure of the amount of moisture in the air compared to the maximum amount of moisture the air *could* hold at that temperature. There are two ways to control RH; 1) raising room temperature such as by adding heat and 2) removing moisture from the air using a mechanical device such as an air conditioner or dehumidifier. This research study explored both strategies. A dehumidifier, for example, removes moisture from the air and adds heat to the air.

Florida weather is hot and humid for about six months of the year. During that period, dew point temperatures, for the most part, remain steadily above 70°F. For a period of about three months, dew point temperatures average in the 74-75°F range (with daily average drybulb temperature of about 82°F), and outdoor RH averages about 77%. When vacant houses are left unconditioned, the indoor drybulb temperature floats up and down in response to solar radiation exposure, sky temperature, and ambient air temperature, while the average indoor dew point temperature is close to that outdoors. Because of solar heat passing through windows and solar heating of the exterior envelope of the structure, the indoor temperature of a stand-alone residence is usually about 4 to 5 degrees higher than outdoors, averaging in the range of 86 to 87°F during the three hottest and most humid Florida months. (Note that most if not all sources of internal heat generation have been turned off during the vacancy.) The degree of heating of the house depends upon a number of factors; the degree of shading of the roof and walls, the exposure of windows to solar radiation, and the solar absorptivity of the exterior surfaces of the building.

Improvements in the energy efficiency of house envelopes over time impacts indoor RH. Houses that are designed to be more energy efficient, with better window orientation and shading and SHGC and U-values, better insulation, and more highly reflective envelope surfaces will remain cooler, and for that reason will experience higher indoor RH when mechanical systems do not intervene.

CHARACTERISTICS OF THE RESIDENCES

Experiments were done in two Phases, with data collection occurring in 2004 and 2005, in a total of seven residences (actually only six residences because one was used in both Phases). Testing was performed to characterize duct airtightness, house envelope airtightness, and the natural infiltration rate (house characteristics are shown in Table 1).

Duct airtightness was tested by sealing supply and return grills. A calibrated blower depressurized the ductwork to -25 pascals while a blower door depressurized the house to -25 pascals at the same time. The result is called $Q_{25,out}$, which is the leakage to outdoors when the ductwork is at -25 pascals with respect to (wrt) outdoors.

House airtightness was measured by means of a blower door, using a multi-point pressure test. The test result is called ACH50, or air changes per hour at 50 pascals.

The natural infiltration rate was determined by tracer gas decay. A tracer gas (nitrous oxide) was thoroughly mixed in the house air, and with all mechanical systems turned off, concentrations of the tracer gas were recorded at typically four locations inside the structure over an approximate 2 hour period.

Four of the six test-homes had 2.5-ton central air conditioning (AC) systems with heat pump, gas, electric strip heating, and electric strip heating, respectively. Houses 4 and 6 had 3.5-ton AC systems with gas furnaces.

Table 1. Characteristics of the residences used in the vacant house study.

House #	Building Type	Year	Size (ft^2)	AC capacity (tons)	# Stories	Heating type **	Duct $Q_{25,out}$	RLF (%)	ACH50	Natural Infiltration (ach)
1	Split level	1965	1950	2.5	2	GHC	71	NA	8.7	0.43
2*	Stand alone	1960	1100	2.5	1	HP	60	0.8	8.5	0.05
3	Single-wide	1985	900	2.5	1	ER	437	2.1	24.4	0.38
4	Duplex	2002	1722	3.5	1	GF	199	13.2	6.6	0.17
5	Stand alone	2003	2317	3.5	2	GF	270	13.1	7.6	0.36
6	4 story condo	~1975	1136	2.5	1	ER	NA	0.0	17.1	0.35 ***

* This house was used in both Phases 1 and 2.
** GHC = gas hydronic coil, HP = heat pump, ER = electric resistance, and GF = gas furnace
*** Tracer gas decay-measured natural infiltration originating from both outdoors and from adjacent spaces within the building.

The reader will notice that in some of these six houses there is not a strong correlation between house airtightness and the natural infiltration rate. In previous work, the authors have found that dividing house airtightness (ACH50) by 40 yields, on average, a fairly good prediction of the house natural infiltration rate (Cummings et al., 1990, 1991). This rule of thumb does not predict well for these houses.

House airtightness can be thought of as the size of the hole in the envelope and infiltration as the air flow rate through that hole. Houses 1 and 2 provide a sharp contrast. While both houses have comparable airtightness, about 8.5 ACH50, the natural infiltration rate is more than eight times greater in House 1 than House 2. An important factor in naturally-driven air flows is complementarity of holes. When the wind blows or when stack effect (driven by outdoor-indoor temperature difference) is occurring, it is necessary for there to be openings at both sides of an enclosure for substantial flow to occur. House 2 has block walls on slab-on-grade construction, with no leakage in the floor, little to no leakage at the floor to slab connection, and relatively little leakage in the walls, windows, and doors. Most of the House 2 leakage exists in the ceiling, especially at the top plates (wall to attic junction) and some in the ductwork. House 2 is like an open soda bottle – it is wide open, but little air can flow into or out of it. There are holes at the top, but few holes at the bottom to allow wind or stack driven air flow through the building.

By contrast, House 1 has leakage at both the bottom and the top of the house. As is common to split level homes, it has a two-car garage that sits adjacent to the lowest floor and below portions of the top floor. Penetrations from the garage into the house represent leak pathways at the bottom of the house. Furthermore, House 1 is about twice the height of House 2, so the stack effect driving force for House 2 is about twice as great.

In Phase 1, experiments were performed in three stand-alone residences.

- House 1, a split-level home with block and frame construction built in 1965 located in Merritt Island, Florida
- House 2, a single-story block home built in 1960 located in Cocoa, Florida
- House 3, a low-mass single-wide mobile home fabricated in 1985 and located in north Merritt Island, Florida.

In Phase 2, experiments were performed in four residences; two stand-alone homes, a duplex, and a multi-story condominium unit.

- House 2, a single-story block home built in 1960 located in Cocoa, Florida (also used in Phase 1);
- House 4, a relatively new block-construction duplex;
- House 5, a stand-alone single-family two-story home in Merritt Island, Florida; and
- House 6, a third-story condo unit located in a four-story building, surrounded by conditioned space on five of six possible sides. It is important to note that (according to the property manager) approximately 90% of the 44 condominium units located in this building were unoccupied during the summer and that owners were encouraged to set their thermostats to 80^{o}F during their departure (the purpose: to avoid musty odors in the spaces). Also, one of the seven supply registers for the AC systems provides air to large corridors. Since there are no returns from the corridor, the corridor is pressurized and the individual condo units are depressurized when the AC systems operate. This also has the effect of increasing the infiltration rate of the condominium space (both from outdoors and from adjacent conditioned spaces) when the AC system is operating.

While all of the houses were furnished, the amount of furnishings in the mobile home (House 3) was estimated to be only 40% of a fully occupied residence.

EXPERIMENTS PERFORMED

Experiments were performed in three homes during the period June through October 2004 (Phase 1) and June through November 2005 (Phase 2).

Phase 1. Six Phase 1 experiments were performed in three stand-alone residences (Houses 1, 2, and 3 in Table 1):

1) no space conditioning as the baseline (allowing the house to “float”)
2) AC thermostat set to 85^{o}F or 83^{o}F for 24 hours per day
3) AC set at 74^{o}F for two hours from 3-5 AM, and set at 89^{o}F for the remainder of the day
4) dehumidifier controlled by onboard humidistat
5) dehumidifier on a timer (typically 3 hours per day)
6) space heating controlled at 89^{o}F 24 hours per day

Phase 2. Five Phase 2 experiments were performed in two stand-alone residences (Houses 2 and 5), a duplex (House 4), and a condominium unit (House 6):

1) AC set at 71^{o}F for two hours from 3-5 AM, and set at 89^{o}F for the remainder of the day
2) AC set at 80^{o}F from 9 PM to noon (15 hours per day)
3) dehumidifier on a timer (typically 3 to 6 hours per day)
4) dehumidifier controlled by humidistat
5) space heating controlled by humidistat

Note that floor fans were used with the dehumidifiers to distribute the heat and dryness produced by the appliance throughout the residence. Typically, we placed the dehumidifier in a shower or kitchen sink to reduce the risk of moisture damage in case of condensate drainage problems. Typically one floor fan would move air from the bathroom where the dehumidifier was located, and a second fan would move the hot and dry air into the main space of the house.

The time durations (number of hours per day) listed in the "experiments performed" listed above can be considered typical; however, the equipment operation times were varied, in some cases, depending upon the size of the home or the natural infiltration rate. This was especially true for Houses 1 and 6. In House 1, for example, which had a high natural infiltration rate, the dehumidifier runtime was increased from 3 hours per day to 15 hours per day to meet the desired humidity control objective and the "AC set at 74^{o}F" runtime was increased from 2 hours to 4 hours per day to meet the desired humidity control objective.

In Phase 2, the effect of higher infiltration rates was explicitly studied in House 2, with experiments 1, 2, and 3 being performed at multiple infiltration rates. The reason for examining multiple infiltration rates is because higher infiltration introduces more water vapor into the space, potentially raising the indoor RH level. House 2 had a very low natural infiltration rate of only 0.05 air changes per hour (ach) which was operational during the Phase 1 experiments. During the Phase 2 experiments, higher infiltration rates of 0.15, 0.22, 0.30, and 0.45 ach were induced by operation of a variable speed, calibrated exhaust fan. Since it took extra time to examine multiple infiltration rates, only three of the experiment types were performed in House 2 (Table 2).

Experiments generally occurred during the period June through October/November (months of the year when Snowbirds are most likely to be absent from their homes). Since five experiments were performed in each home, and for each experiment it was desirable to obtain a variety of weather conditions, experiments were cycled through at approximately 14 day periods. In this manner, data could be obtained for each experiment under a variety of temperature, humidity, and solar radiation exposures.

Table 2. Experiments carried out in the four residences of Phase 2.

HOUSE #	AC ON at 71^{o}F from 3-5 AM	AC ON at 80^{o}F from 9 PM-noon	Dehumidifier with Timer	Dehumidifier with Humidistat	Space Heating with Humidistat
2	X	X	X		
4	X	X	X	X	X
5	X	X	X	X	X
6	X	X	X	X	X

PHASE 1 EXPERIMENTAL RESULTS

The results of various experimental controls are discussed here. Line graphs (figures) used to show temperature, RH and energy use can be found at the end of this paper organized by Phase 1 and Phase 2.

No Conditioning

As previously indicated, the average outdoor RH for summer weather in central Florida is about 77%. Providing no conditioning, or letting the building "float", yielded indoor conditions that were 4.8, 6.1, and 4.2^{o}F warmer than outdoors (due primarily to solar radiation striking the house), respectively, in Houses 1, 2, and 3. As a result, indoor RH averaged 62%, 69%, and 73% in the three houses (Figures 1 and 2 show July and August RH for Houses 2 and 3). Since the objective was to keep RH below 65% most of the time, only House 2 experienced acceptable RH without mechanical intervention. This does not mean, however, that Houses 1 and 3 would experience mold problems without mechanical intervention. It just means that the risk of mold is higher in these houses.

The reader may have noticed that the RH in House 2 was lower than expected, given that the house was cooler relative to outdoors than say House 1. Several factors may be involved. First, the house is located on the mainland, so outdoor temperatures are slightly higher than the other two houses which are located on Merritt Island. Second, the dew point temperature may be slightly lower on the mainland compared to the other two houses which are more closely surrounded by adjacent rivers and canals. Third, there is some indication that the flat roof of House 2, and the shallow vented "attic" space of House 2, performs passive dehumidification. While beyond the scope of this paper, a brief description of a possible mechanism follows.

During the hot hours of the day, when the sun is shining on the roof, the roof decking (plywood), the pine truss members, and insulation materials are heated and experience desorption (moisture driven from the surfaces of those materials). Desorption draws moisture from these materials, adding water vapor to the attic air, and raising the attic dew point temperature. Wind speeds are higher during the day, so attic ventilation rates are higher during daytime hours. This ventilation transports high moisture-content (high dew point temperature) air from the attic to outdoors. This in turn further lowers the attic RH, which in turn can increase the rate of desorption, and reduce the moisture content of the materials in the attic. The ceiling gypsum board is also dried.

At the end of the day, the attic temperature cools, raising RH. The elevated RH drives moisture onto the surface of attic materials (wood, insulation, etc.) by a process called adsorption. Because the materials were thoroughly dried during the day, they have the potential to draw a large amount of vapor from the attic air, lowering the dew point temperature in the attic substantially. Because the attic ventilation rate is much lower at night (lower winds during nighttime hours), the attic air remains much dryer than outdoors (in terms of dew point temperature). As a result, the average dew point temperature in the attic is below that outdoors. Because of air exchange and vapor diffusion through the ceiling plane, the dryness in the attic transfers to the occupied space causing lower than expected indoor RH.

AC thermostat set to 85^{o}F or 83^{o}F

Setting the AC system to 85^{o}F or 83^{o}F is neither effective nor energy efficient. On cool and cloudy days, when the moisture removal capability of the AC system is required most, the AC system does not operate at this elevated thermostat setting. On hot and sunny days, when the moisture removal of the AC system is required least, the AC system runtime is maximized, producing lower than required indoor RH and increasing energy consumption. Also, the electrical demand from this approach is antithetical to the interests of the utility, since energy consumption is maximized during the hottest hours of the hottest days, exactly when the utility's system-wide demand is peaking. Figure 3 illustrates the cycling behavior of this control strategy, with no runtime on cooler and cloudier days and considerable runtime on hot and sunny days. Figure 4 shows that the electrical demand from "AC set to 85^{o}F" occurs at exactly the wrong time from the utility's perspective.

AC set at 74^{o}F from 3-5 AM

This approach was found to be nearly ideal. The AC system is programmed to run at full capacity for a two-hour period in the early morning hours. Because the outdoor conditions are coolest, the AC system operates most efficiently, with greater capacity, and with a colder coil (hence yielding better moisture removal). Because the system runs for two hours continuously, part-load degradation in latent cooling performance is avoided. During this two-hour period, indoor RH is lowered considerably.

In House 2, for example, indoor RH declines from about 54% to about 39% during a three-hour period AC system operation period (Figure 5; Figure C). After the AC system shuts down, RH rises rapidly to about 46%, and then drifts upward to 54% during the remainder of the 24 hour period. Note that even though we had programmed the system to operate from 3 to 5 AM, the AC system ran for three hours from 2 to 5 AM each day because the existing thermostat had "intelligent design" that "instructed" the system to come on 1 hour early to help it meet the setpoint objective by the start of the control period.

Because buildings have moisture capacitance (the ability to store moisture in building materials by means of adsorption), the dryness produced during the 2-hour AC "on" period creates dryness in the building materials (by means of desorption). For the 22 hours that the AC system is not operating, the dryness stored in the carpets, furniture, books, wallboard, etc. acts as a reservoir of dehumidification potential, keeping the indoor RH levels lower.

In House 1, which has a high infiltration rate, two-hour operation yielded marginal results with RH falling primarily in the range of 65%-70%. Extending operation to *four* hours (3 - 5 AM and 10 AM - noon) yielded average 59% RH (Figure 6).

In House 3 (mobile home), the results are inconclusive in part because the data collection for this home did not include the hottest summer months (Figure 7). The home reached the thermostat setpoint before the air conditioner had run the intended two hours each morning, in large part because the structure has low mass and only an estimated 40% of normal furnishing levels (and therefore low thermal storage capacity). For this reason, a thermostat setting of 71^{o}F was used in the homes of Phase 2 to increase the likelihood that the AC would operate continuously during the full two-hour runtime.

Dehumidifier controlled by built-in humidistat

The 40-pint dehumidifiers used in this study had onboard humidistats. We set the humidistats to control the room RH to 62%. However, since the control dial has no RH indication (just "dryer" and "less dry"), we had to adjust the control by estimating initial setpoint, then observing room RH as the unit cycled on and off . Figure 8 shows the results in House 3 (mobile home). With the dehumidifier operating about 40% of the time, indoor RH was fairly stable at about 61% throughout the 16 day period.

In House 1, which is large and has a high infiltration rate, the dehumidifier ran at full capacity 24 hours per day. After an initial RH pull-down period, when RH went from 76% to 65%, indoor RH gradually declined and stabilized at about 62%.

Dehumidifier controlled by a timer

Figure 9 shows the change in RH in the living room of House 2 with the operation of a dehumidifier for three hours from 8 to 11 AM (set to a low RH setpoint to keep it operating whenever the timer permits) with the dehumidifier located in the nearby kitchen. During the dehumidifier operation period, the indoor RH declines by about 21 percentage points, from 62% to 41%, and then drifts upward throughout the day. A substantial portion of the decline in RH results from a typical 5-6 degree F increase in the living room space temperature. About 50% of the decline in living room RH is attributable to the rise in temperature and the remaining 50% decline in living room RH results from moisture being removed from the air by the dehumidifier. While RH in the living room declined by 21 percentage points during the 3-hour dehumidifier operation period, the RH reduction in other portions of the house was much less, with RH declining by about 4 percentage points during this 3-hour period in the farthest bedroom. Note that a floor fan operated coincidently with the dehumidifier to move heat and dryness from the living room to other portions of the house.

In House 1, it was recognized that 3 hours per day of dehumidifier operation would not achieve the desired results since 24-hour per day dehumidifier operation only achieved 62% RH when controlled by the built-in humidistat. Given that continuous dehumidifier operation could only just barely meet our target RH, a timer was installed to operate the dehumidifier for 15 hours each day, from 9 PM – noon. This control strategy reduced energy consumption by 37.5% (compared to 24 hour per day operation) and avoided all demand impacts during the utility's peak demand period. Figure 10 shows a regular pattern of dehumidifier operation each day, with sharp downward spikes in relative humidity starting at 9 PM and a gradual upward movement in RH starting at 12 PM (noon). Average daily indoor RH remains fairly stable at about 60% during the period of September 17 – 24 (excluding moderate daily fluctuations), with daily excursions generally in the range of 58%-62%. Indoor temperature averaged 88.8^{o}F over this six-day period. Indoor dew point temperature averages 73.0^{o}F during this period, while outdoor dew point temperature (at a Cocoa weather station about 9 miles away) was only a couple degrees F higher. Thus, we can conclude that a large portion of the decrease in indoor RH occurs because of elevated indoor temperature caused by the heat generated by the dehumidifier.

A steep climb was, however, observed in indoor RH, from about 58% to about 74% with the approach of Hurricane Jean on September 25, with winds of 80-90 miles per hour. The infiltration rate of the house was clearly increasing with the increasing wind speed, and this infiltration was driving high dew point temperature air into the building. Power disruption occurred part-way into the storm, causing both dehumidifier operation and data collection to cease after September 25.

Space heating to 89°F

This approach, which involves heating the house with the central space heating system, was effective at reducing RH in all three homes. This result is not surprising. Florida summer dew point temperatures are typically in the range of 72°F to 75°F. Heating the indoor temperature to 89°F on a typical summer day increases the moisture capacity of the air and, as a result, reduces indoor RH to 60% to 64%. If the home is going to be vacant during the cooler months such as May and October when the dew point temperatures are lower, then maintaining this high indoor temperature will produce even lower RH. In House 2, for example, indoor RH was 54% over a period from September 27-October 13 when the outdoor dew point temperature averaged 69°F. In House 3, indoor RH was 59% over a period from September 30-October 14 when the outdoor dew point temperature averaged 69°F. The difference in RH between Houses 1 and 3 results from House 1 being about 2 degrees F warmer than House 3.

During periods with lower outdoor dew point temperatures, the same RH can be achieved at a lower space temperature. If, for example, it is October and the outdoor dew point temperature is 68°F, the indoor temperature required to produce 62% RH would be 82°F. This suggests the potential to reduce heating energy use if the system is controlled by a humidistat. This option is examined in Phase 2.

SUMMARY OF PHASE 1

Of the five RH control approaches performed in Phase 1 (in three stand-alone residences), two are not recommended. Three were identified as effective and generally energy efficient, and worthy of additional study.

Ineffective

Two methods were identified as "not effective".

- Letting the house "float" (no space conditioning) cannot reliably achieve RH below 65% most of the time. Extended periods of RH at 70% and above were observed in two of the three homes, especially during cooler and cloudier weather. There are ways that vacant houses could be made hotter when unconditioned. Houses could be modified, by design, to allow more heat to enter the building during vacant periods, by such measures as running the air handler unit (AHU) during hot hours of the day (assuming the ducts are at least partially in the attic), uncovering skylights purposely intended to add heat to the house, etc.
- Setting the AC system to 85°F, or even 83°F, is not sufficient, especially on humid and cloudy days, to achieve RH control.
    - On cool and cloudy days, when the moisture removal of the AC system is required most, the AC system does not run.
    - On hot and sunny days, when the moisture removal of the AC system is least required, the AC system run time is maximized, especially during the time of day when the utility's system-wide demand is peaking.

Effective

The following three methods show considerable promise, each showing the ability to control indoor RH with desirable energy and peak demand impacts. None of these methods stands out as being substantially better than the others within the limited sample of homes.

- Running the AC system "flat out" for two hours in the early morning appears to work well in a majority of homes and under a wide range of weather conditions. In homes with high infiltration rates, AC operation time may need to be extended to adequately control RH. Lower thermostat settings may be necessary during cooler weather for light mass (i.e., manufactured) homes.
- "Dehumidifier on a timer" is effective and reliable in controlling RH at a reasonable energy cost. Dehumidifier run time must be determined based on the size and airtightness of the house. A floor fan (or two) can be operated on the same schedule to distribute the heat and dryness produced by the dehumidifier.
- Heating the house to about 89°F lowers indoor RH quite effectively for nearly all hours of the summer without removing moisture from the room air. Energy use is moderate for the period June through September (especially in homes using heat pumps), but increases substantially in spring and fall.

More details regarding this Phase 1 research project can be found in (Cummings et al., 2005) available at : http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1487-04/index.htm.

PHASE 2 EXPERIMENTAL RESULTS

The experiments of Phase 2 had some similarities but also some important differences from Phase 1.

- Of the five Phase 2 experiments, two were repeats from Phase 1; 1) AC ON from 3-5 AM and 2) dehumidifier on a timer.
- Three new experiments were also added; 1) AC ON at 80^{o}F from 9 PM-noon; 2) dehumidifier controlled by a humidistat, and 3) space heating controlled by a humidistat.
- An important difference in Phase 2 was the inclusion of a condominium unit located in a multi-story building. Since this an embedded condo unit, surrounded on five sides by conditioned space, space conditions were heavily controlled by the surrounding space within the building.
- Additionally, the infiltration rate of one of the houses (House 2) was varied to examine the effect upon RH control. Because experiments were run at several infiltration rates, there was time for only three of the five RH control strategies (approaches 1 – 3) to be tested in House 2.

<u>The first approach, *AC set at 71^{o}F from 3-5 AM*</u> (fan AUTO), was examined in all four houses. This approach was a repeat from Phase 1 with the temperature setting lowered from 74^{o}F to 71^{o}F. In House 2, the infiltration rate was varied. Generally, this approach yielded good results. For the test periods examined, this paper presents average RH during the period (and peak RH in parentheses).

- In House 2 (1-story), this approach provided good RH control at all levels of infiltration. Test results at four different levels of infiltration, 0.05, 0.15, 0.30, and 0.36 ach, during September (2004) and June, October/November, and September 2005, respectively, finds a general pattern of rising indoor RH as infiltration increases. RH levels averaged 48% (58% peak), 56% (64% peak), 60% (63% peak), and 59% (63% peak) for these four infiltration rates, respectively. Energy use averaged 7.2, 6.5, 2.4, and 6.7 kWh per day during these tests, respectively, for this AC unit that consumes about 2700 watts . The reason for the variation in AC energy use is as follows. During the tests at 0.05 ach, the thermostat actually ran the system for nearly three hours each day (because the thermostat, unknown to the authors, has anticipatory temperature control logic). The lower energy use for the 0.30 ach testing occurred because the weather during this October/November test period was sufficiently cold so that the AC satisfied the thermostat setpoint of 71^{o}F in less, on average, than one hour's time. This occurred, in part, because the AC unit was relatively oversized at 2.5 tons for 1100 square feet of floor space.
- In House 4 (duplex), this approach provided good RH control during June, September/October, and November test periods. RH levels averaged 57% (67% peak), 57% (67% peak), and 57% (60% peak), respectively. Energy use averaged 6.9, 6.9, and 0.2 kWh per day, respectively. The AC essentially did not run during the cool November period. A relatively low infiltration rate (0.17 ach) also helps maintain interior dryness during the AC OFF periods.
- House 5 (2-story), this approach provided unacceptable RH control during June/July and October test periods. RH levels averaged 64% (69% peak) and 68% (72% peak), respectively. Energy use averaged 7.3 kWh per day during each test. Two factors contribute to this failure. First, large duct leaks reduce the effectiveness of the AC system while the system is operating. $Q_{25,out}$ is a large 270 cfm and the return leak fraction is 13.1% (meaning 13.1% of the air entering the AHU originates from outside the air boundary of the house envelope). Second, the relatively high natural infiltration rate (0.36 ach) allows substantial flow of water vapor into the house during the 22 hours per day that the AC system is not operating. Return leaks bring additional heat and water vapor into the house, and thereby reduce the effectiveness of the AC system as a dehumidifier. However, supply leaks can also cause high moisture content air to be drawn into the house, if the supply leakage amount exceeds the return leakage amount. When dominant supply leaks push air to spaces outside the house air boundary, for example, it causes depressurization of the house, which in turn causes hot and humid air to be drawn into the house. Furthermore, supply leaks significantly reduce net latent and sensible cooling capacity, making the AC system less effective at lowering house RH.
- In House 6 (condo), this approach provided unacceptable RH control during a June test period (Figures 11 and 12) when the AC system ran for 2.5 hours each day (2.5 hours instead of 2 hours because of thermostat control logic). RH averaged 66.5% (78% peak). Energy use averaged 7.7 kWh per day. The relatively high infiltration rate (0.35 ach) allows substantial flows of water vapor into the space from outdoors and from adjacent spaces (split unknown). Expanding the AC run time from 2.5

to four hours yielded a significant improvement (to acceptable RH control) during a June/July time period (Figures 13 and 14) when RH averaged 61% (70% peak). The expanded AC run time was insufficient, however, to provide acceptable RH control during a September test period (Figures 15 and 16) when RH averaged 62% but the peak was 76%. Energy use for the expanded AC operation averaged 12.0 kWh per day. An interesting pattern is observed for the condominium building, which affects RH in the condo unit being studied. On sunny days (which are also typically hotter days) the RH level in the building as a whole drops, because most of the condo units are set to 80°F (per the building manager). The drier air produced by AC systems located in other condo units throughout the building causes a substantial drop in RH in the test condo unit. Conversely, during cloudy weather, RH levels in the test condo rise substantially apparently because the AC units throughout the building run little and therefore allow RH to rise.

The second approach, *AC set at 80°F from 9 PM - noon (or 9 PM to 7 AM)* (fan AUTO) was examined in all four houses. Generally, this approach yielded good results but it has some disadvantages.

- In House 2 (1-story), this approach provided marginal-to-very good RH control depending upon the weather patterns and various infiltration rates. Weather conditions are more dominant than the infiltration rate. Energy consumption is strongly weather dependent. Because our monitoring periods were relatively short, it is difficult to make definitive energy use conclusions. Based on the available data, it appears that this approach will consume about \$30/month in a typical 1800 ft^2 home.
    - At 0.15 ach, this approach yielded very good RH control. The RH level averaged 53% (62% peak).
    - At 0.30 ach, this approach yielded exceptionally good RH control during a hot and sunny period in July. The RH level averaged 50.5% (56% peak).
    - At 0.30 ach, this approach yielded marginal RH control during a moderately cloudy and very high dew point temperature period in October (including 60 mph winds from Hurricane Wilma). The RH level averaged 63% (66% peak).
    - At 0.45 ach, this approach yielded good RH control during typical August weather. The RH level averaged 57% (63% peak).
    - Because of limited attic insulation, and the continuous exhaust operation that was causing the house to draw air largely from the attic, AC operation in this house was very sensitive to solar radiation levels. We conclude, therefore, that "AC at 80°F from 9 PM to 7 AM" is not an energy efficient means to control RH, because the AC runs too much on hot days and too little on cloudier days. An approach that provides a fixed amount of AC operation per day (such as the "AC at 71°F from 3 AM to 5 AM") is more effective and more energy efficient. Even better, an approach that operates the AC system in response to indoor RH would be best. Using RH control, the AC system would then run less on hot days and more on cloudier days, therefore running only when needed. A discussion of this alternative approach which the authors believe will produce improved RH control is presented at the end of this paper.
- In House 4 (duplex), this approach was examined at three thermostat setpoints.
    - This approach with an 80°F setting provided good RH control during a July test period. The RH level averaged 57% (62% peak). Energy use averaged 7.2 kWh per day. Temperature, RH, and power results are shown in Figures 17 and 18.
    - When the thermostat setpoint was raised to 82°F, the AC system continued to provide good RH control. RH levels averaged 58% (62% peak), 61% (65% peak), 61% (67% peak), and 60% (64% peak) during July, August, October, and November test periods, respectively, at the 82°F setting. Energy use averaged 3.8, 1.9, 0.0, and 0.0 kWh per day during these tests, respectively. No AC operation occurred during the latter two test periods. Temperature, RH, and power results for a July test period are shown in Figures 19 and 20.
    - When the thermostat setpoint was raised to 84°F, the AC system ran little during typical July/August weather consuming an average of 0.6 kWh/day. While the RH level averaged 60% (64% peak) during this very hot period, the authors concluded that this approach with the 84°F thermostat setting would certainly not provide adequate RH control during cooler and cloudier weather.
    - A relatively low infiltration rate (0.17 ach) helps maintain interior dryness during periods when the AC system is OFF.

- In House 5 (2-story), this approach was examined at three thermostat setpoints.
    - This approach with an 80^{o}F setting provided good RH control during a July test period when scheduled for 15 hour per day operation. The RH level averaged 58% (65% peak). Energy use averaged 17.8 kWh per day . This approach with an 80^{o}F setting provided very good RH control during a July test period when scheduled for 10 hour per day operation. The RH level averaged 55% (61% peak). Energy use averaged 15.1 kWh per day.
    - When the thermostat setpoint was raised to 82^{o}F, the AC system provided marginal RH control during an August test period. The RH level averaged 62% (65% peak). Energy use averaged 5.1 kWh per day . During a cool and cloudy period in September, the AC system provided unacceptable RH control. The RH level averaged 70% (76% peak). Energy use averaged 1.9 kWh per day. Because of the relatively high natural infiltration rate of this house, considerably more AC run time is required compared to House 1 in order to control indoor RH. Figure 21 illustrates that an 82^{o}F setting results in little to no AC run time during cloudy and humid weather, and very elevated indoor RH.
    - When the thermostat setpoint was raised to 84^{o}F, the AC system provided good RH control during an exceptionally hot and sunny period in late July. The RH level averaged 59% (63% peak). Energy use averaged 4.4 kWh per day. An assessment was made that the 84^{o}F thermostat setting would certainly not provide adequate RH control during cooler and more cloudy weather, and would most likely not even provide adequate RH control during average summer weather conditions.
- In House 6 (condo), this approach was examined at several temperature settings.
    - At an 80^{o}F setting, this approached produced unacceptable RH control during a July test period (Figure 22). The RH level averaged 71% (72% peak). Since the AC did not turn ON during this one-week test period, energy use was 0.0 kWh per day.
    - At a 77^{o}F setting, this approach also produced unacceptable RH control during a July 7-11 test period Figures 23 and 24. The RH level averaged 75% (81% peak). This five-day period was a generally cloudy period with exceptionally high outdoor dew point temperatures. Energy use averaged 4.3 kWh per day. The modest AC operation time was totally unable to match the high rate of moisture introduction produced by the relatively high infiltration rate (0.35 ach).
    - At a 74^{o}F setting, this approach did produce acceptable RH control during a July test period Figures 25 and 26. The RH level averaged 58% (70% peak). This was a moderately sunny period with high outdoor dew point temperatures. Energy use averaged 13.7 kWh per day. The greatly increased AC operation time was able to match the high rate of moisture introduction produced by the relatively high infiltration rate (0.35 ach).
    - It is clear that dwelling units located inside of larger, multi-story buildings behave differently from stand-alone houses (or even duplexes). Because this embedded condo unit receives little heat from outdoors (sensible cooling load), a set-point of 80^{o}F or even 77^{o}F (from 9 PM to 7 AM) results in insufficient load to drive the AC system operation. This is especially true in this building where other condo AC units are set to 80^{o}F and therefore operate considerably during hot and sunny weather. The entire building RH drops substantially during sunny and hot weather. The dryer air produced throughout the building by the other AC systems causes a substantial drop in RH in the test condo unit. In this building, best practice would require a control strategy that runs the AC much more on cloudy and cooler days.

The third approach, *dehumidifier on a timer from 8 - 11 AM*, was examined in all four houses. Generally, good results can be obtained with sufficient dehumidifier run time (in each case a 40-pint dehumidifier was used along with one or two floor fans). The length of required dehumidifier runtime is in part a function of house size and more importantly the natural infiltration rate of the house.

- In House 2 (1-story), this approach provided marginal-to-good RH control depending upon the weather patterns and various infiltration rates.
    - When we include a test performed in Phase I Project (0.05 ach), results are available for five levels of infiltration 0.05, 0.15, 0.22, 0.30, and 0.45 ach. These five tests occurred during August/September (2004), October, September, August, and August/September,

respectively. There is no general pattern of rising indoor RH as the infiltration rate increases. Solar radiation and outdoor dew point temperature are more dominant than the infiltration rate. RH levels averaged 56% (63% peak), 65.5% (67% peak), 63% (68% peak), 59% (62% peak), and 63.5% (65% peak), respectively. Energy use averaged 2.1 kWh per day for each of these test periods, including floor fans. Figure 27 shows the temperature, RH, and power response for 3 hours per day dehumidifier operation with the ventilation rate set to 0.22 ach. The plot shows that during cloudy but humid weather (with dew point temperature about 75°F), indoor RH peaks at over 70% in one room of the house (further from the dehumidifier).

- o Project research staff developed estimates of dehumidifier runtime required <u>for this house</u> to maintain acceptable indoor RH most of the time.
  - 1.5 hours per day for 0.05 ach.
  - 2.5 hours per day for 0.15 ach.
  - 3.5 hours per day for 0.30 ach.
  - 4.5 hours per day for 0.45 ach.

- In House 4 (duplex), this approach provided good RH control during a September test period Figures 28 and 29. RH levels averaged 62% (67% peak). Energy use averaged 1.9 kWh per day. A relatively low infiltration rate (0.17 ach) also helps maintain interior dryness during the dehumidifier OFF periods.
- In House 5 (2-story), this approach provided marginal RH control during a test period in August. RH levels averaged 66% (68% peak). Energy use averaged 2.2 kWh per day, including floor fan energy. A relatively high natural infiltration rate (0.36 ach) causes indoor RH levels to increase fairly rapidly during the dehumidifier OFF periods. Because the house is larger than the other residences and because of the higher natural infiltration rate, project staff estimate that the dehumidifier run time would need to be increased to 5 hours per day to achieve acceptable RH levels, which would require an average 3.7 kWh per day energy use.
- In House 6 (condo), this approach provided acceptable RH control during a test period in July/August when the dehumidifier operation time was six hours per day (Figure 30). RH levels averaged 57% (64% peak). Energy use averaged 3.7 kWh per day, including floor fans. A relatively high natural infiltration rate (0.35 ach from outdoors and adjacent spaces combined) causes indoor RH levels to increase fairly rapidly during the dehumidifier OFF periods. Note that operation of the dehumidifier pushes up the indoor temperature from 80°F to 82.5°F as a result of the heat given off by the dehumidifier. About 5 percentage points of the RH reduction occurring in this condo unit is the result of heating of the indoor space.

<u>**The fourth approach, dehumidifier controlled by a humidistat**</u> (set to a humidistat control point of 62% RH), was examined in three of the four houses. The end result was humidity control deficiency in all three houses. However, the authors conclude that a dehumidifier controlled by a humidistat *could* have achieved acceptable RH control in all of the residences, had there not been humidistat performance issues. Specifically, it was difficult to set the humidistats to the desired control setting and some of the humidistats exhibited drift problems. In Houses 4 and 5, the humidistats were located in the central zone of the house even though the dehumidifiers were located in perimeter locations. It should also be emphasized that the authors were aware of some of the humidistat deficiencies and made their best efforts to set the humidistats so that they would yield good RH control without wasting energy.

- In House 4 (duplex), this approach provided marginal RH control during an August test period. RH levels averaged 64% (68% peak). Energy use averaged 0.6 kWh per day. A relatively low infiltration rate (0.17 ach) helps reduce the dehumidifier operation time by limiting the entry rate of outdoor water vapor. In order to achieve acceptable RH control, the humidistat would have to be set to a lower setting. The 62% setting that was used produced about 64% in the living room and 68% in the bedroom. It appears that a setting of 60%, for this particular humidistat, would likely achieve our objective of controlling RH at 65% or lower during most hours. Dehumidifier energy use would of course increase substantially with the lower RH setting, but would still be quite reasonable. Given that three hours of dehumidifier run time per day (with timer control and 2.1 kWh per day energy use) yielded 62% (67% peak), suggests that dehumidifier energy use of about 3 to 4 kWh per day would yield the desired RH control for this house.
- In House 5 (2-story), this approach provided unacceptable RH control during two test periods in September and October. RH levels averaged 68% (70% peak) and 68.5% (69% peak), respectively. Energy use averaged 2.4 and 1.5 kWh per day, respectively, including the floor fans. In order to achieve acceptable RH control,

the humidistat would have to be set to a lower setting. The 62% setting produced an average RH of about 67% in the living room and 68% in the bedroom. It appears that a setting of 58%, for this particular humidistat, would likely achieve our objective of controlling RH at 65% or lower during most hours. Dehumidifier energy use would increase substantially with the lower RH setting, but would still be moderate. Given that three hours of dehumidifier run time per day (with timer control and 2.2 kWh per day energy use) yielded an average 66% RH (68% peak), suggests that dehumidifier energy use of about 5 to 10 kWh per day would yield the desired RH control for this house. The split-level house in the Phase I study (House 1), which had a high natural infiltration rate of 0.43 ach, required 15 hours per day to maintain acceptable RH. Given that House 2 (Phase II) has a lower natural infiltration rate and operates at higher temperatures (because of the extensive east and west window areas), it is likely that 8-10 hours per day (5.9 to 7.3 kWh per day) would be required for this house. Even at 10 hours per day, the monthly energy cost (at $0.12 per kWh) would only be $26.

- In House 6 (condo), this approach provided marginal RH control during a period in August (Figure 31). RH levels averaged 64% (70% peak). While the humidistat was set to 57%, actual room RH averaged 63% (in the bedroom where the humidistat was located) for about one week, and then without explanation room RH jumped up to about 68% (while the dehumidifier cycled). This indicates that there is need for improved humidistats. Energy use averaged 1.8 kWh per day. Setting the humidistat to a lower level, such as 54%, would likely allow the dehumidifier to meet our RH control objective of keeping RH at or below 65% most of the time. Given that six hours of dehumidifier operation (with timer control) was sufficient to yield acceptable RH control (58% average and 64% peak with 3.7 kWh per day energy use), we would expect that energy use with an appropriate humidistat RH setting would use on the order of 4 kWh per day. At $0.12 per kWh, this would still be a modest $15 per month energy cost.

<u>The fifth approach, space heating controlled by a humidistat</u>, was examined in three of the four houses. Generally, it appears that space heating controlled by a humidistat can achieve acceptable RH control in all of the tested residences (including the condo). Use of a humidistat (compared to use of a thermostat set to 89^{o}F) to control the heating system reduces energy use dramatically, especially in cooler months such as May, October, and November.

- In House 4 (duplex), this approach provided acceptable RH control. Heat is provided by a gas furnace.
  - During a September test period, with the humidistat set to 62%, the room RH level averaged 62% (65% peak) as can be seen in Figure 32. Energy use averaged 105,000 Btu per day. If the system had been a heat pump with a COP of 4 (at summer temperatures), the heating energy use would have been 7.7 kWh per day (or $28 per month).
  - During a test period in October/November, with the humidistat set to 62%, the room RH level averaged 60% (62% peak). Energy use averaged 12,400 Btu per day over the entire period. The heating system was operational for only one of the 26 test days, because outdoor dew point temperatures were low enough to control indoor RH to below the humidistat setpoint. If the system had been a heat pump with a summer weather COP of 4, the heating energy use would have been 0.9 kWh per day (or $3.30 per month). This illustrates how a humidistat can eliminate most of the heating requirement during cooler portions of the snowbird season.
- In House 5 (2-story), this approach provided marginal RH control. Heating is provided by a gas furnace.
  - During an August test period, with the humidistat set to 62%, the room RH level averaged 65% (67% peak). Energy use averaged 0 Btu per day. The heating system NEVER came on because the weather was very hot and sunny, and this house has extensive window area on the east and west sides. This resulted in an interior temperature hot enough (averaging about 89^{o}F on the first floor) to maintain RH below the humidistat setpoint the entire 10-day period.
  - During a five-day period in October, with the humidistat set to 62%, the first floor and second floor RH levels averaged 66% (73% peak). Heat energy use averaged 6,859 Btu per hour on an average basis (7,929 Btu per hour including AH fan energy) over the five-day period. The heating system operated on only four of the five test days. On the fifth day, a cold front moved into the area, lowering outdoor dew point temperatures from 75^{o}F to 38^{o}F. As a result, indoor RH dropped rapidly and caused the heating system to turn off.

    - This house illustrates the fact that the humidistat can eliminate heating system operation during both cooler days when outdoor dew point temperatures are dropping, and hot and sunny days when solar heat gains to the house produced indoor temperatures that are already in the range of 88^{o}F to 90^{o}F.
- In House 6 (condo), this approach provided acceptable RH control. Heating is provided by electric resistance heating elements located in the air handler.
    - During a September test period, with the humidistat set to 62%, the room RH level averaged 62% (64% peak) with an average room temperature of about 85^{o}F. Energy use averaged 15.9 kWh per day.
    - During a test period in October, with the humidistat set to 62%, the room RH level averaged 62% (67% peak). Energy use averaged 21.1 kWh per day over the entire period. One can see in Figure 33 that once the outdoor dew point temperature dropped significantly, the humidistat shut OFF the heating system, thereby saving considerable energy.
    - Given an average heating energy use of 18.5 kWh per day between the two test periods, the heating energy use would be $67 per month. If the system had been a heat pump with a summer-weather COP of 4 (instead of electric resistance heat), the heating energy use would have been 4.6 kWh per day ($17 per month).
    - Furthermore, if all snowbirds in this condo building were to use this space heating approach (instead of the AC at 80^{o}F), then the heating energy use for this condo unit would be much less, perhaps less than $10 per month, because all (or most) of the building heating systems would be operating simultaneously. On the other hand, the approximately 10% of the building occupants who did not leave for the summer would have significantly higher cooling energy use if the surrounding spaces were in the 87^{o}F to 89^{o}F range through much of the summer.

Selecting System Operation Time for Various Infiltration Rates

Experiments carried out at House 2 were done at various infiltration rates for three of the five humidity control approaches. A calibrated exhaust fan drew air from the house continuously at a controlled rate for each test period.

The first approach, *AC set at 71^{o}F from 3-5 AM* (fan AUTO), showed a reasonably clear pattern of response to changes in infiltration. In general, indoor RH increased with increasing infiltration. With ach at 0.05, 0.15, 0.30, and 0.36 ach, the resulting indoor RH averaged 48%, 56%, 60%, and 59%, respectively. Based on these results, the authors developed the following AC runtime recommendations for the various infiltration rates for this house; 0.5 hours per day for 0.05 ach, 1.3 hours per day for 0.15 ach, 1.9 hours per day for 0.30 ach, and 3.0 hours per day for 0.45 ach. The relatively short runtimes recommended for this house reflect in part the fact that the AC system (2.5 tons capacity) was considerably oversized for this house. Air change rates can be measured using tracer gas decay methods which are expensive, however, they can be estimated for slab on grade homes in the southeast by dividing a house tightness measurement (ACH50) by 40 (Cummings et al. 1991).

The second approach, *AC set at 80^{o}F from 9 PM - noon (or 9 PM to 7 AM)* (fan AUTO), showed a less clear pattern of RH response to changes in infiltration. Changes in indoor RH appear to be more closely related to weather and less to infiltration. With ach at 0.15, 0.30, 0.30, and 0.45 ach, the resulting indoor RH levels were 53%, 50.5%, 63%, and 57%, respectively. In the first approach, "AC set at 71^{o}F from 3-5 AM", the AC run time is not related to weather. The AC unit runs 2 hours each day largely independent of the weather (except during a very cool November period). In the second approach, "AC set at 80^{o}F from 9 PM - noon (or 9 PM to 7 AM)", AC run time is highly dependent upon weather. Consequently, the AC system removes much more water vapor from the indoor air on hot and sunny days than on cool and cloudy days.

The third approach, *dehumidifier on a timer from 8 - 11 AM*, showed little RH response correlation to changes in infiltration. With ach at 0.15, 0.22, 0.30, and 0.45 ach, the resulting indoor RH was 65.5%, 63%, 59%, and 63.5%, respectively. It is difficult to draw guidance from this information regarding the length of dehumidifier operation time required for good RH control as a function of infiltration rate.

SUMMARY OF PHASE 2

Of the five RH control approaches performed in Phase 2, four show promise for controlling RH in vacant homes. Energy cost estimates in the following discussion are based on electricity at $0.12 per kWh. Heating costs are based on the heating systems being a heat pump.

“AC at 71^{o}F from 3-5 AM” has been found to be effective. In homes with higher infiltration rates, the AC system runtime may have to be increased. This approach has the advantage that the AC system is already in place, and in many cases a programmable thermostat is also available (and can be fairly easily installed if it is not). Also, thermostats and AC systems are proven and relatively reliable technologies. The energy cost for this approach is modest, typically running $20 - $25 per month for a home with a 3-ton system.

“AC set at 80^{o}F from 9 PM – noon” was neither consistently effective nor energy efficient. On cooler and cloudier days, the AC system did not run sufficiently to achieve the desired RH control. On hot and sunny days, the AC system ran longer than required, producing RH levels considerably below our target, and wasting energy. Energy use cannot be readily estimated with this approach because AC operation time is weather driven, and we had only a few weeks of data upon which to make an assessment.

“Dehumidifier on a timer” can be effective. Some trial and error is required to set the necessary operation time. Running a 40-pint dehumidifier for three hours per day was found to be adequate in small to moderate sized homes with relatively low infiltration rates. In these homes, energy cost is modest, typically running about $10 - $12 per month, including power for floor fans. In homes with higher infiltration rates, dehumidifier run times had to be increased substantially. In the case of House 1 in Phase 1, the dehumidifier had to run 15 hours per day. The dehumidifier is an effective humidity control approach in vacant homes in significant part because the dehumidifier is a relatively high-efficiency space heater. The heat given off by the dehumidifier raises the indoor temperature which in turn lowers RH. There are some disadvantages to this approach. 1) There is equipment to purchase. 2) The dehumidifier condensate drain may overflow, so it would be best to locate the device in a shower, sink, or other place with a drain. 3) The dryness and heat generated by the dehumidifier, often in a bathroom, must be distributed by floor fans (or other fans). 4) A timer must be purchased and installed with sufficient power rating to operate the typical 40-pint dehumidifier (about 600 watts) plus one or two floor fans (50 to 200 watts). It is preferable to have a timer with battery back-up so that the time-of-day operation (e.g., 8 – 11 AM) remains constant over an extended period. 5) There is some uncertainty that the dehumidifier, timer, and fans will all continue to operate as intended over the 3 to 6 month period that the house is left unattended.

“Dehumidifier controlled by a humidistat” can be effective. In theory, it should provide ideal control of the dehumidifier, eliminating the need for trial and error selection of operation time. When more RH control is needed, the humidistat will cause the unit to run longer. When less RH control is needed, the humidistat will reduce the runtime. This simplifies set-up and saves energy when environmental conditions permit. In practice, however, problems exist with humidistat control. Humidistats were tested in a laboratory environment and several problems were found. 1) For some humidistats, RH control drifts from the apparent humidistat setpoint, and the reason for this drift is unknown. 2) Deadbands are large (12 to 23 percentage points for many units), and this large deadband can lead to excessive swings in indoor RH. In some cases, the large deadband can result in the system never turning OFF or never turning ON. 3) It is difficult to set the humidistat to 62% (or other desired setting) because the control dial is often not particularly accurate and deadbands are often quite large. In general, there is need for substantial improvement in humidistat performance. Energy cost would be modest, and somewhat less than the already frugal “dehumidifier on a timer”.

“Space heating controlled by a humidistat” can be effective. In Phase 1, heating the space to 89^{o}F was found to be effective but used excessive energy during cooler weather. Controlling the space heating system by means of a humidistat can yield excellent energy savings compared to the fixed 89^{o}F setting, especially during the cooler months of May, October, and November. The effectiveness of the humidistat is dramatically illustrated in Figure 33, where a drop in outdoor dew point temperature is immediately accompanied by the heating system shutting down. As with dehumidifier control, it is important that the humidistat perform well. Energy costs are likely to be on the order of $25 to $35 per month for homes in the 1500 to 2000 ft^{2} range, and assuming a heat pump. During cooler months, energy use with humidistat control would be greatly reduced compared to heating to a constant 89^{o}F. In order to maintain 62% RH in the space, the indoor temperature need only be 14^{o}F higher than the outdoor dew point temperature, thus greatly reducing the amount of heat required during periods with lower outdoor dew point temperatures.

Comments on embedded condominium units

Embedded apartments or condominium units do not respond in the same manner as stand-alone residences, or even duplexes. Units located in multi-story buildings will respond in very individual ways depending upon a number of variables. One important variable is the degree to which the unit is surrounded by other conditioned spaces. Another important variable is the amount of solar radiation that can enter through windows, which is related of course to the window area, orientation, and shading. Some condo units, such as House 6 in this study, have drawn hurricane shutters which keep out essentially all solar radiation. An additional factor is the dryness of the air in the surrounding portions of the building, and the air exchange rate between the condo unit and the surrounding spaces. House 6 was located in a building that experienced considerable variation in indoor dew point temperature – lower dew point temperatures when hot and sunny weather caused the AC units (typically set at 80°F) to run more.

Since this study examined only one embedded condominium unit, there is need for study of additional units. This unit had a relatively high infiltration rate when the AC system was off, and this rate also increased significantly when the AHU operated because of the supply delivering air to the corridor.

More details regarding this Phase 2 research project can be found at the following link. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1626-06.pdf

Additional untested approach

An additional approach is proposed but has not been tested. This approach would control the central AC system by means of a humidistat set to perhaps 62% RH. In this approach the AC system would run only when required by humidistat, and would thus reduce unnecessary energy consumption. There is, however, a hazard that needs to be avoided. This hazard is the possibility that the humidistat might not be satisfied so the AC unit runs continuously and overcools the house. This author (Cummings) has examined a house in which the AC system ran at full capacity for approximately six weeks. Indoor temperatures during Florida summer weather fluctuated in the range of 56 °F to 63°F (daily swings). Since this temperature is substantially below the outdoor dew point temperature, moisture condensation and mold growth occurred extensively throughout the house.

There are a number of circumstances under which this control failure can occur. The RH control setpoint can be set too low. The humidistat deadband (turn on minus turn on RH level) can be too large. The humidistat can fail. A high air infiltration rate can introduce water vapor into the space at a high enough rate so the RH setpoint cannot be achieved. Or the AC system could lose its ability to effectively dehumidify. To overcome this potential risk, it is recommended that a lower temperature limit be implemented (such as 77°F) so that house overcooling can be avoided.

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FIGURES

Figures 1-33 follow this page.

PHASE 1 FIGURES

ASSESSMENT OF THE EFFECTIVENESS AND ENERGY EFFICIENCY
OF HUMIDITY CONTROL APPROACHES IN VACANT FLORIDA HOMES

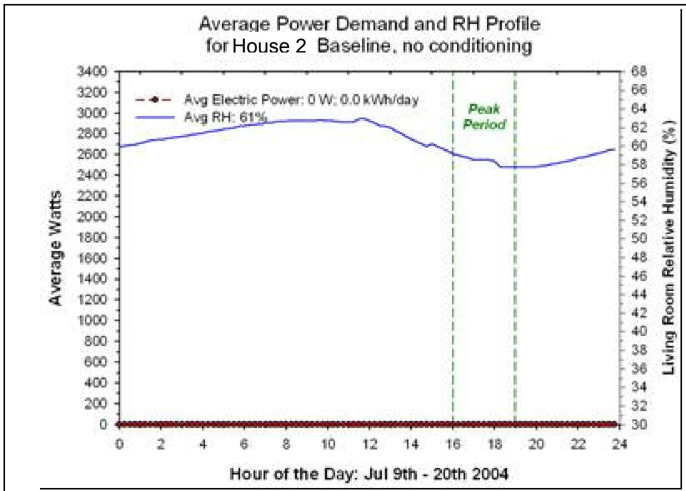
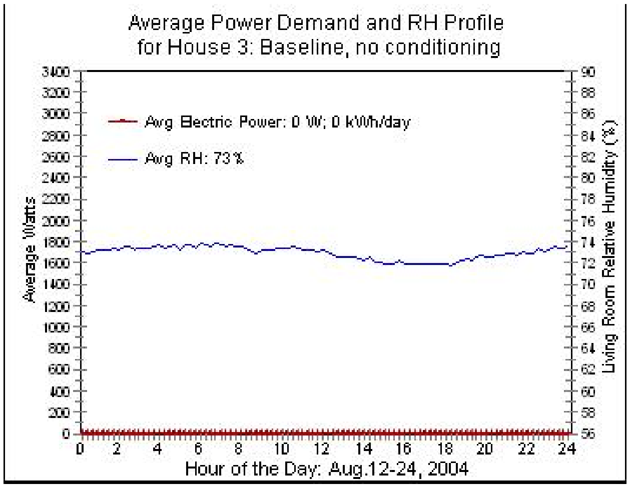


Figure 1



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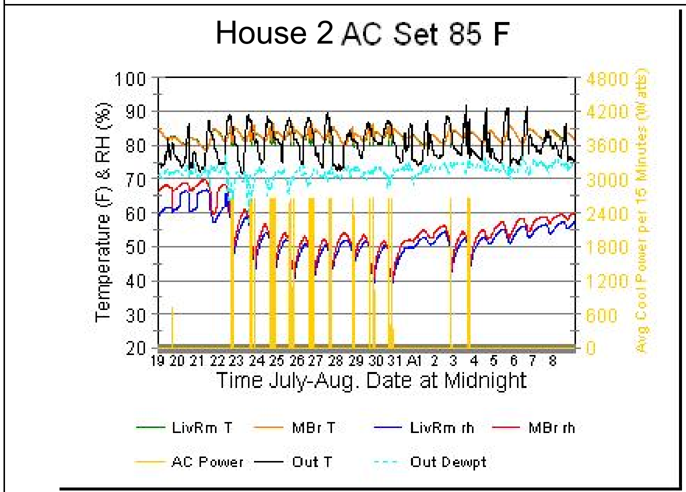

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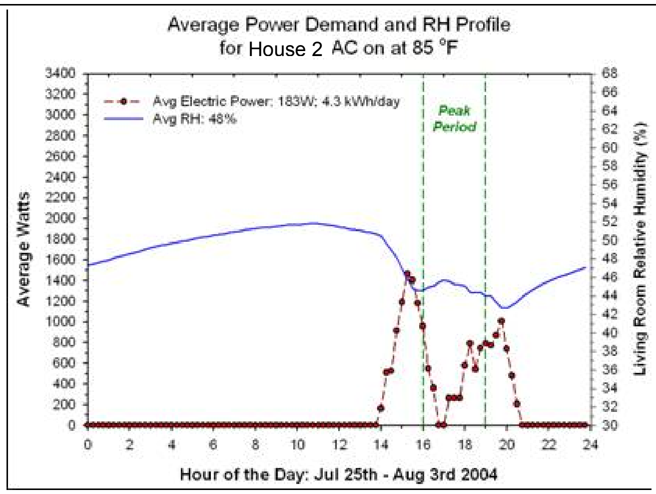

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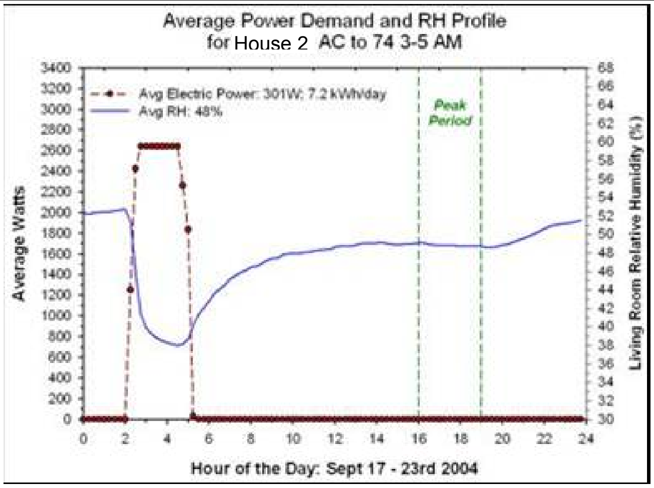

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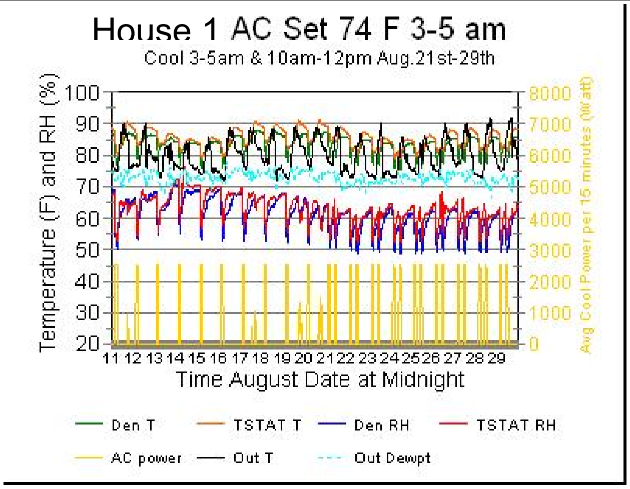

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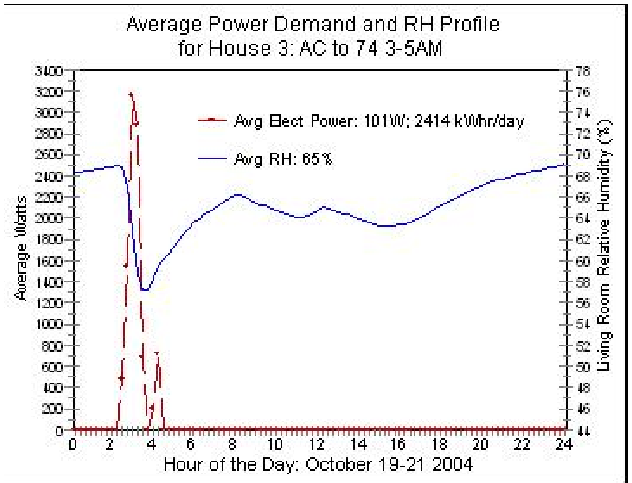

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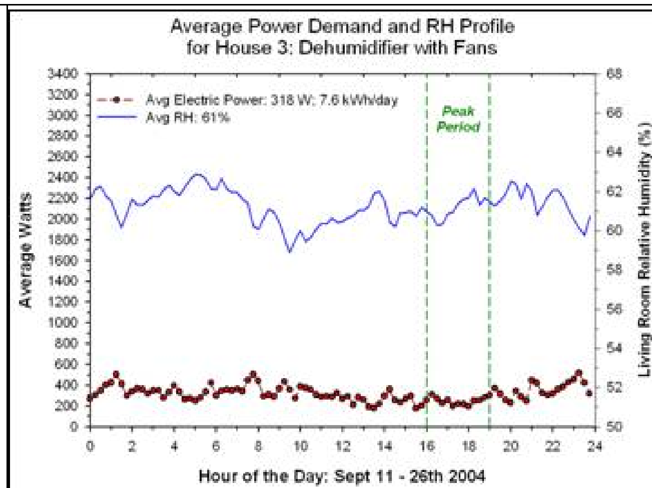

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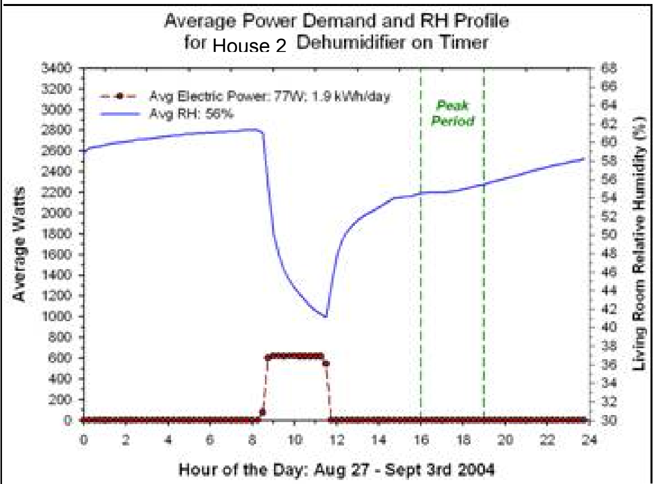

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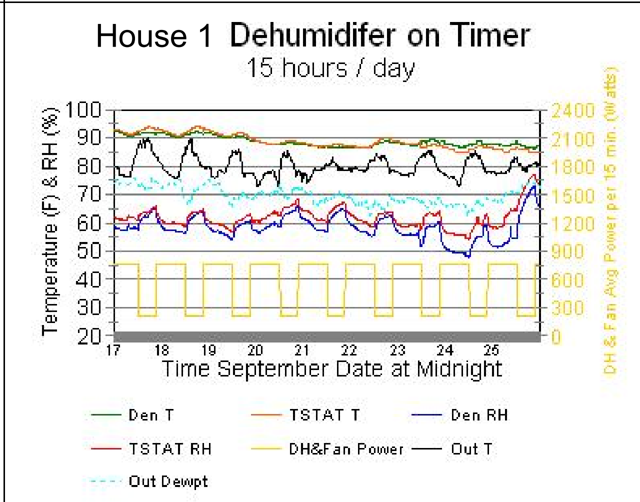
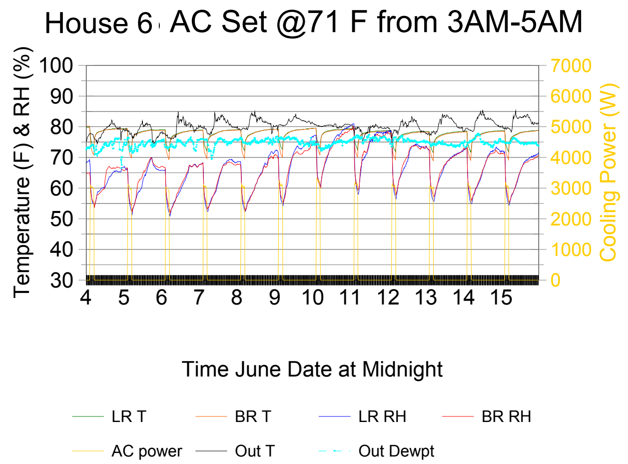


Figure 10

PHASE 2 FIGURES

ASSESSMENT OF THE EFFECTIVENESS AND ENERGY EFFICIENCY
OF HUMIDITY CONTROL APPROACHES IN VACANT FLORIDA HOMES



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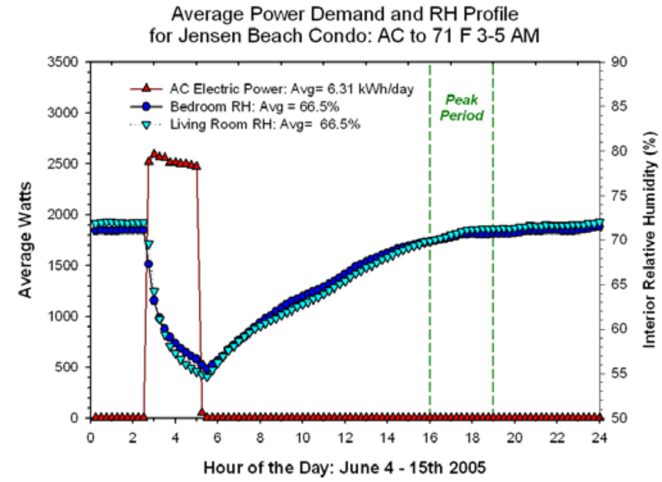

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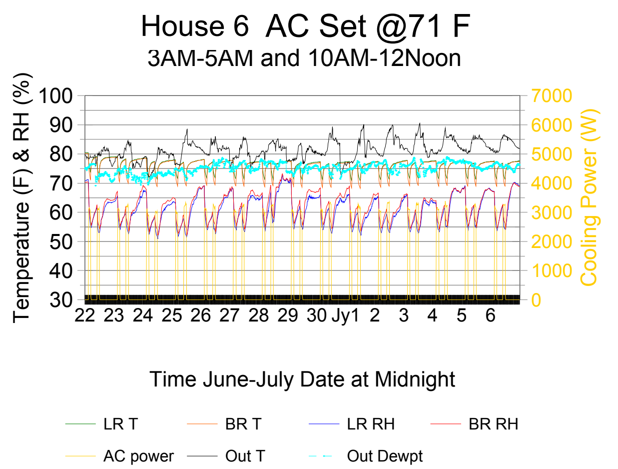

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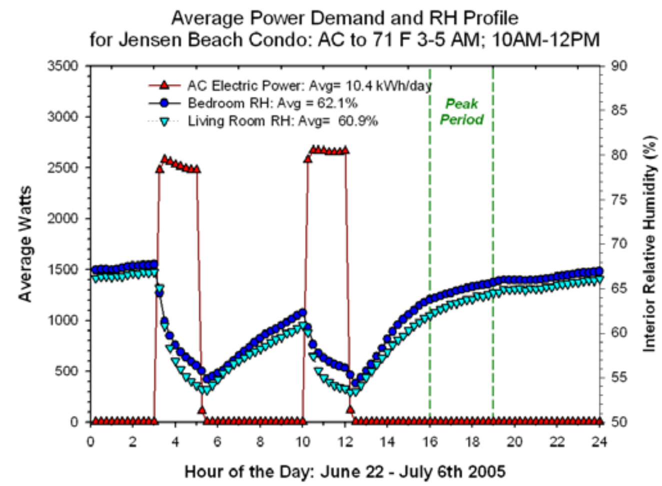

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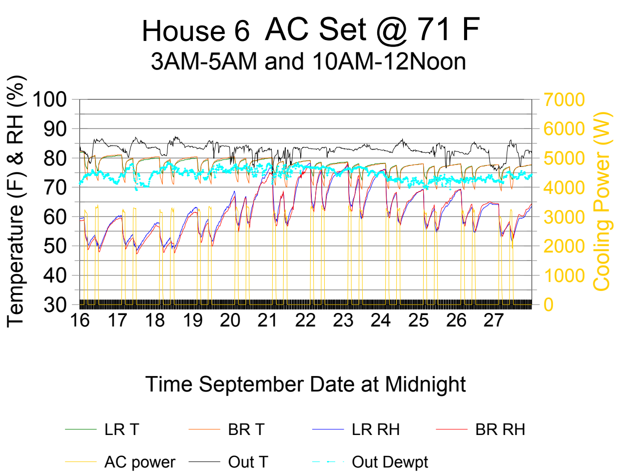

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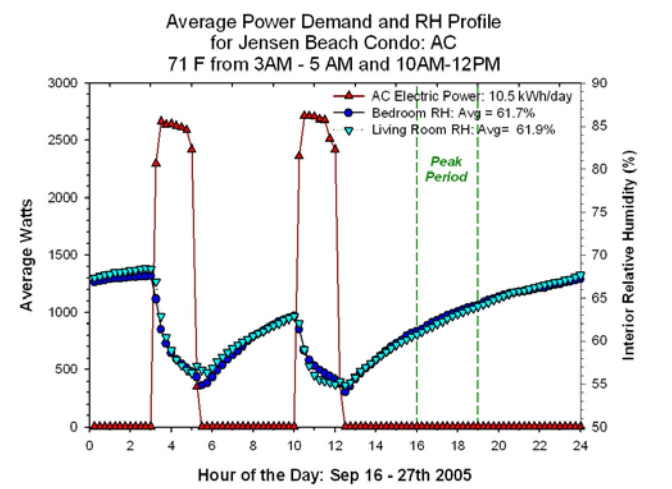

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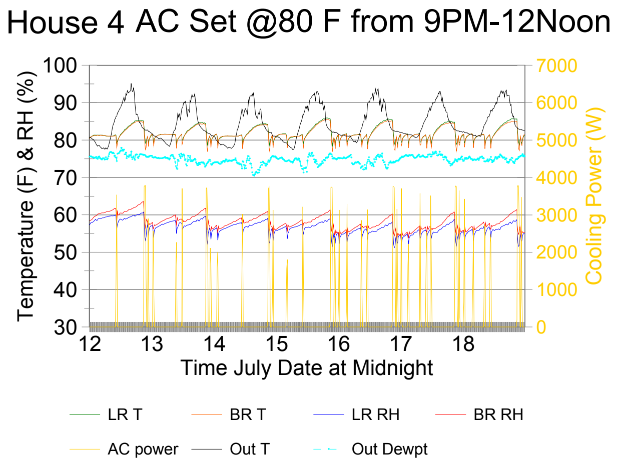

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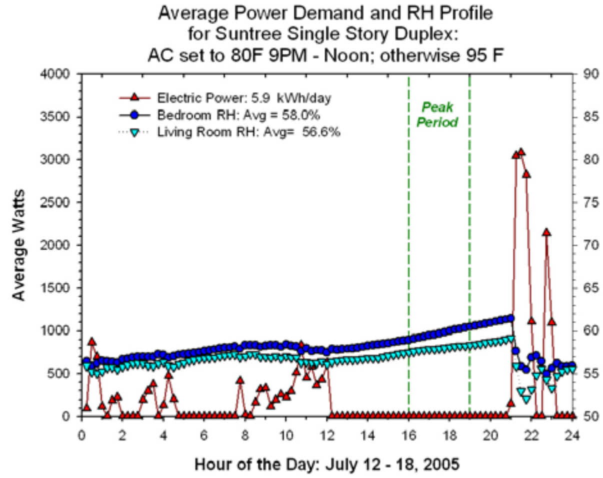

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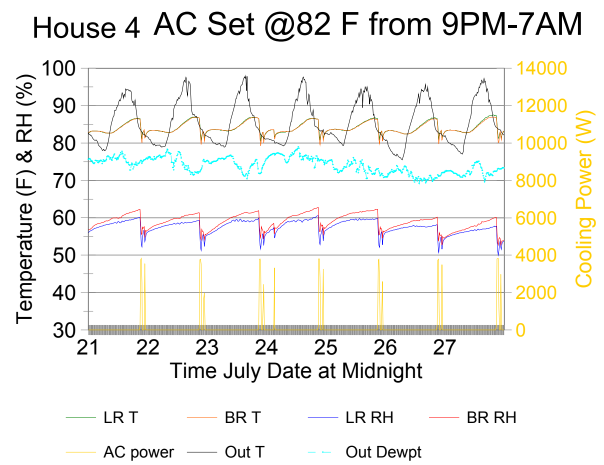

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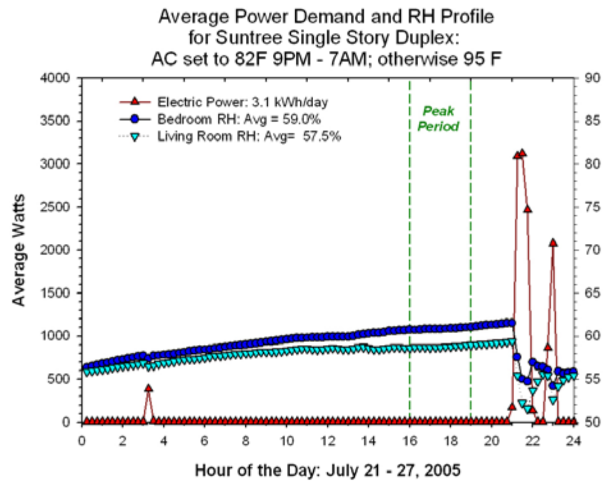

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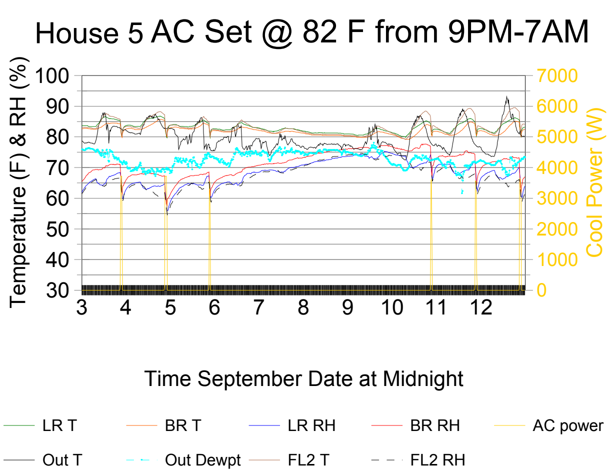

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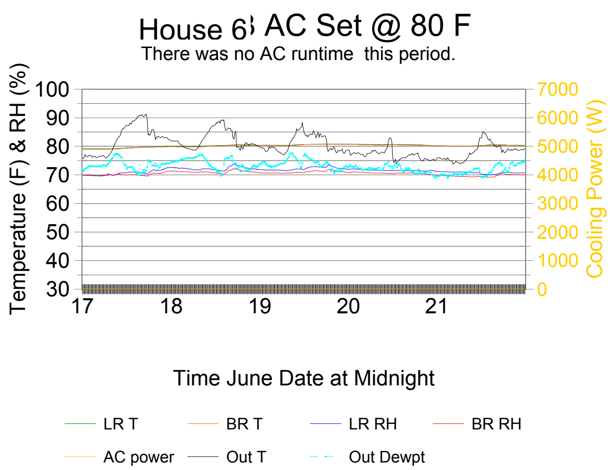

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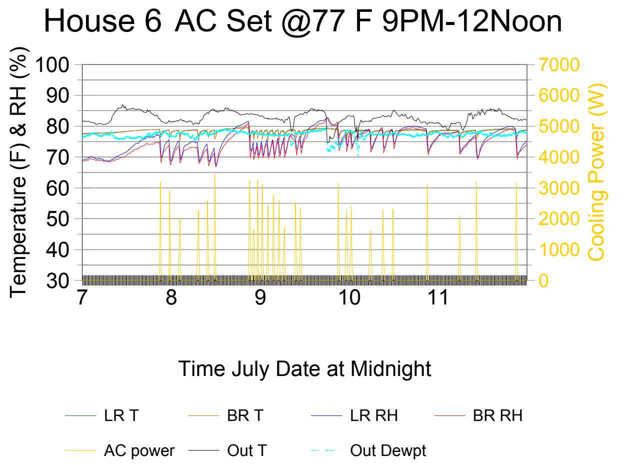

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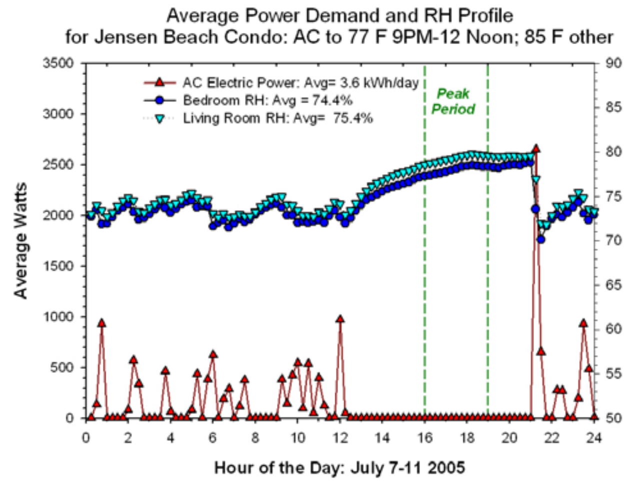

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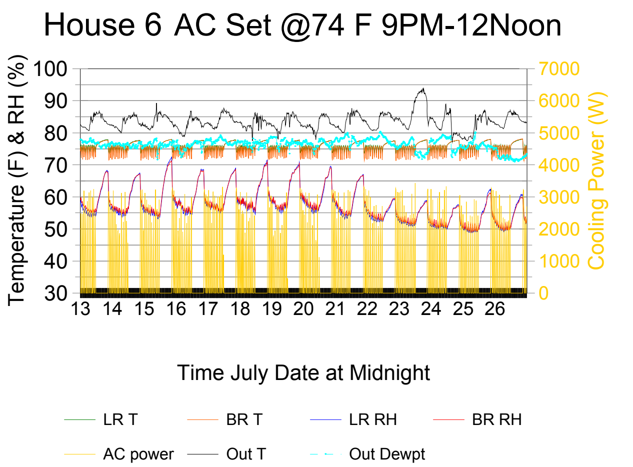

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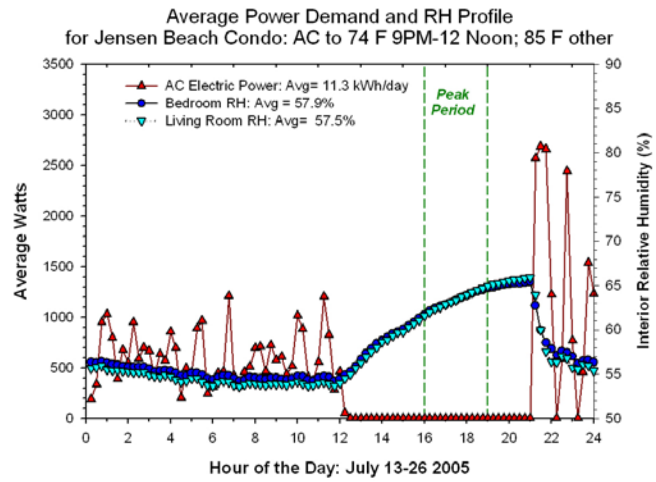

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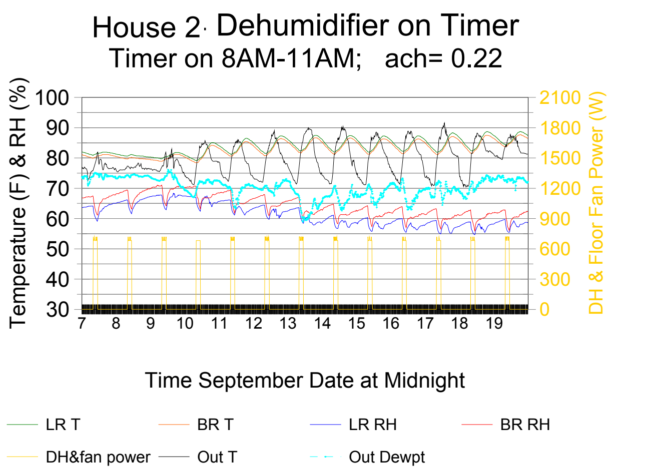

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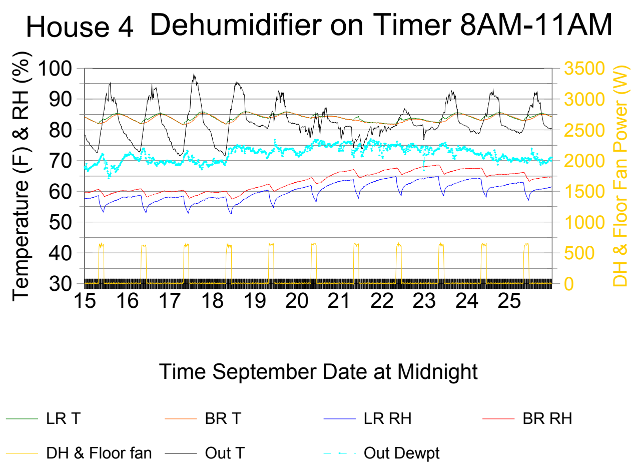

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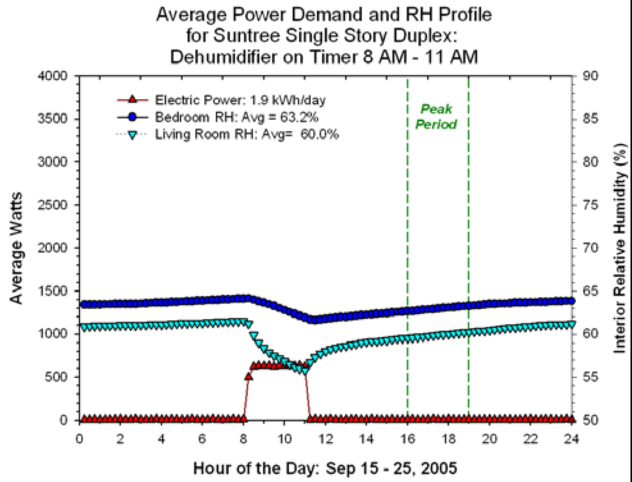

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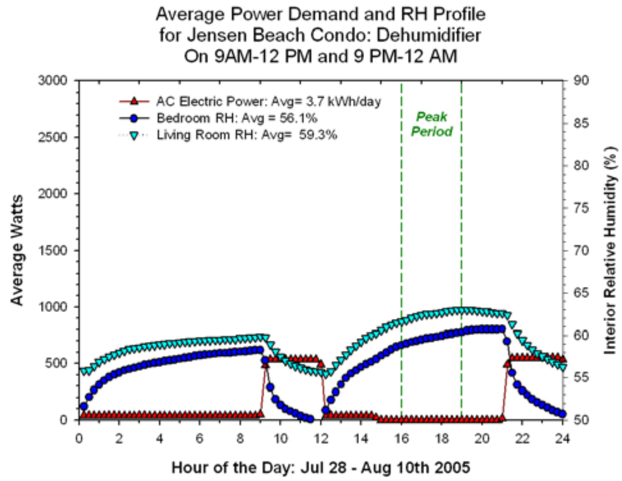

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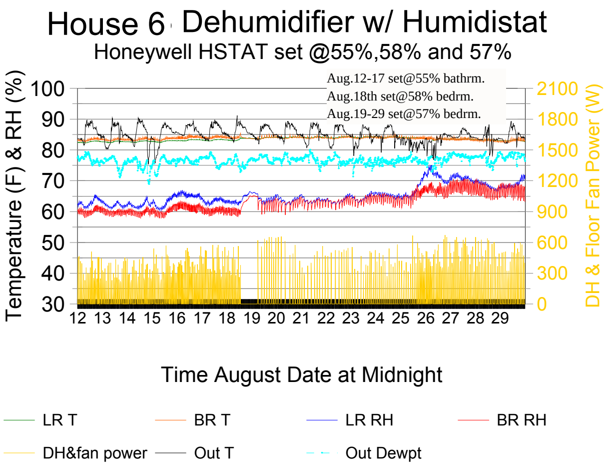

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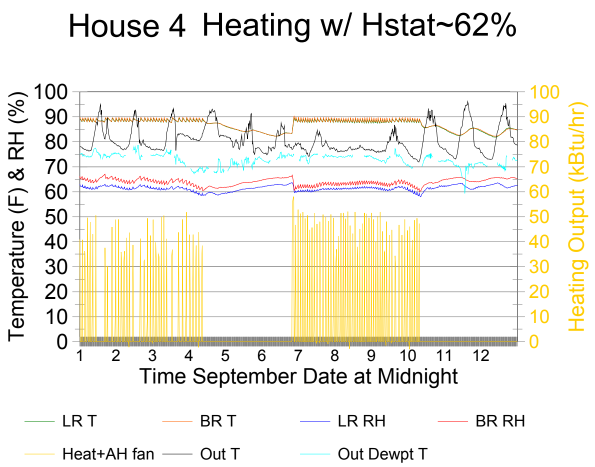

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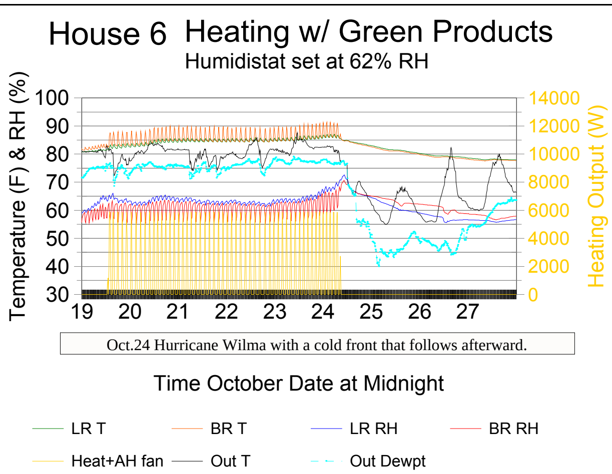

Figure 33

This is the last page of
ASSESSMENT OF THE EFFECTIVENESS AND ENERGY EFFICIENCY OF HUMIDITY CONTROL APPROACHES IN VACANT FLORIDA HOMES.